8334

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01F 27/32

A2

(11) International Publication Number: WO 99/28927

(43) International Publication Date: 10 June 1999 (10.06.99)

(21) International Application Number: PCT/SE98/02160

(22) International Filing Date: 27 November 1998 (27.11.98)

(30) Priority Data:
9704379-8 27 November 1997 (27.11.97) SE

(71) Applicant (*for all designated States except US*): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): LEIJON, Mats [SE/SE]; Hyvlargatan 5, S-723 35 Västerås (SE). JAKSTS, Albert [CA/SE]; Ekorrvägen 13, S-722 43 Västerås (SE). SCHÜTTE, Thorsten [SE/SE]; Bangatan 5 B, S-722 28 Västerås (SE). LIU, Rongsheng [CN/SE]; Bangatan 1 F, S-722 28 Västerås (SE). FROMM, Udo [DE/SE]; Liegatan 33, S-724 67 Västerås (SE). SASSE, Christian [DE/SE]; Drottninggatan 4 B, S-724 64 Västerås (SE).

(74) Agents: KARLSSON, Leif et al.; L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).

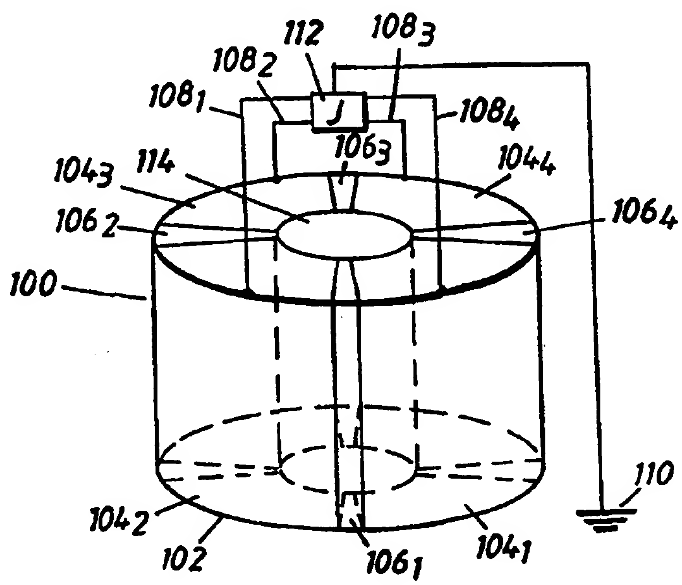
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: A POWER TRANSFORMER/REACTOR

(57) Abstract

The present invention relates to a power transformer/reactor (100) comprising at least one winding (22_1, 22_2). The winding/windings (22_1, 22_2) comprises/comprise at least one electric conductor, a first semiconducting layer (14) arranged around the conductor, an insulating layer (16) arranged around the first semiconducting layer (14), and a second semiconducting layer (18) arranged around the insulating layer (16). The winding/windings (22_1, 22_2) is/are enclosed in a container (102) filled with a liquid, said liquid accomplishing a cooling.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

A POWER TRANSFORMER/REACTOR

According to a first aspect, the present invention relates to a power transformer/reactor.

During all transmission and distribution of electric energy transformers are present, their task being that of permitting a change of electric energy between two or more electric systems which normally have different voltage levels. There are transformers for all effect regions from the VA to the 1000 MVA region. As to the voltage region there is a spectrum up to the highest transmission voltages used today. For the transmission of energy between the electric systems, electromagnetic induction is used.

By transmission of electric energy, also reactors are present as an important component, for example during phase compensation and filtration.

The transformer/reactor which is the object of the present invention belongs to the so-called power transformers/reactors with a rated effect from some 100 kVA to above 1000 MVA with a rated voltage from 3-4 kV and up to very high transmission voltages.

Generally, the primary task of a power transformer is to permit an interchange of electric energy between two or more electric systems which mostly have different voltages of the same frequency.

A conventional power transformer/reactor comprises a transformer core, hereinafter named core, made of laminated, preferably oriented sheet, normally made of silicon iron. The core is comprised by a number of core legs connected by yokes. Around the core legs, there are a number of windings which are normally called primary, secondary, and control winding. As to power transformers, these windings are practically always arranged concentrically and distributed along the length of the core legs.

Sometimes other types of core constructions might be used, for example thos that are included in so-called shell transformers or in

toroid core transformers. Examples of core constructions are described in DE 40414 amongst others. The core may be comprised by conventional magnetizable materials, such as the oriented sheet mentioned above, or of other magnetizable materials, such as ferrites, amorphous materials, metal threads or metal bands. When it comes to reactors, the magnetizable core may, as is well known, be excluded.

The windings mentioned above are formed by one or more coils connected in series and constituted by a number of turns connected in series. The turns of an individual coil are normally joined to one geometrically continuous unit, physically separated from the rest of the coils.

The insulation system, within a coil/winding on one hand, and between coils/windings and other metal details on the other hand, is normally constituted by a solid cellulose or lacquer based insulation nearest to the individual conducting element and, at the outside thereof, as solid cellulose and liquid, possibly also gaseous insulation. Windings with insulation and possible strut parts will, in this way, represent large volumes that will be subjected to high electrical field strengths that appear in and around the active electromagnetic parts of the transformer. In order to be able to predetermine the dieletrical loads appearing and to obtain a dimensioning with a minimal risk of having an electric breakdown, a good knowledge about the properties of the insulation materials is required. It is also important to accomplish a surrounding environment that does not change or impair the insulation properties.

The most common outer insulation system for high voltage, conventional power transformers/reactors today is comprised by a cellulose material forming the solid insulation and transformer oil forming the liquid insulation. The transformer oil is based on so-called mineral oil.

Apart from a relatively complicated structure, conventional insulation systems also require special manufacturing measures in order to take advantage of the good insulation properties of the insulation syst m. The system should hav a low moisture content, the s lid phas in

th insulation syst m should b well impregnated with the surrounding liquid, and the risk of having remaining gas pockets in the solid phase has to be at a minimum. Therefore, during the manufacturing, a special drying process is performed onto a complete core with windings before the positioning thereof into a box. After positioning into and sealing of the box, the box is emptied from all air by a special vacuum treatment before it is filled with oil. Such a process constitutes a substantial part of the total manufacturing time while, at the same time, it requires extensive engineering resources.

As the process requires a total out-pumping of gas in order to obtain a nearly absolute vacuum, the box or the tank that surrounds the transformer has to be constructed for a total vacuum, resulting in an extra consumption of material and manufacturing time.

Furthermore, mounting on the field requires, in its turn, repeated vacuum treatment, a process that has to be repeated each time the transformer has been opened for some measure or inspection.

It has now proven itself that, by producing windings for the initially mentioned power transformer/reactor made of an insulated electric high voltage conductor with a solid insulation of a kind similar to the one of cables for power transmission, it is possible to obtain a plurality of advantages.

The insulated conductor or cable used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the insulated conductor or cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inn r conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer sur-

rounding this and an outer semiconducting lay r surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

Th insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

In a conventional oil-insulated transformer, the removal transportation of the heat generated through the losses in the core and the winding is executed by means of the oil. Therefore, the oil must circulate in a suitable way through the winding package and subsequently be cooled. The oil can be forced to circulate through the windings, but many manufacturers use self-circulation. In a self-cooled transformer, oil is streaming into the bottom of the transformer box and is successively heated during the passage through the winding. The hot oil leaves the box through the upper part of the latter and is cooled in radiators or coolers.

Through US patent document 1, 481,585 it is also already known to cast windings into concrete. In this case, the winding is comprised by a so-called high voltage cable, the core of which is insulated by means of an impregnated paper or a lacquered or varnished textile material, and where the cable is coated with lead. According to this patent, which by the way was filed in 1919, a cable with the described type of insulation and a fairly rigid metallic shield will not, however, in practice be able to cope with the radiuses of curvature and the bending forces that are needed in transformer windings. The risk of having damages in the insulation, with a subsequent breakdown is large. Thermal variations (heat xpansion) and other m chanical forces might asily give rise to

voids in the insulation, voids that becom th starting point for an lectric breakdown, either immediately or after an affection by the partial discharges in the gas volume. Furthermore, at that time the expression "high voltage" referred to a voltage of approximately some dozens of kV and a rated effect of some MVA, the described cable accordingly not being at all suited to the voltage and effect levels that are referred to by the expression "high voltage" today.

By other winding arrangements, the winding is cooled to a wide extent by horizontal oil flows, the oil flow needing to be controlled by means of barriers. The cooling of the oil is simple by smaller transformers. The walls of the transformer box, possibly provided with plied cooling ribs, will then provide a sufficient cooling surface for the oil flowing down the walls. Together with an increasing transformer size, the loss effect per surface unit grows, and the cooling has to be made more effective. By transformers in the region up to some dozen of MVA, radiators with self-circulation of the oil are often used. Larger transformers are normally provided with compact coolers with circulation pumps and fans, possibly with water cooling instead of air cooling.

The object of the present invention is to solve the problems mentioned above. This is accomplished by means of a power transformer/reactor according to patent claim 1. The power transformer/reactor according to the present invention comprises at least one winding, normally arranged around a magnetizable core of a varying geometry. In order to simplify the following description, the expression "the windings" will be used hereinafter. The windings comprise at least one electric conductor, a first semiconducting layer surrounding the conductor, an insulating layer arranged around the first semiconducting layer, and a second semiconducting layer arranged around the insulating layer. Furthermore, the windings are enclosed in a container filled with liquid, said liquid accomplishing a cooling.

As the winding is constructed in the way defined above, electric fields will be enclos d, r sulting in th substantial advantage of having

an electric field that will be close to 0 in the end region of the coil outside the winding, and in the electric field outside the winding not needing to be controlled. In other words, the electric field is already controlled in this way. This means that no field concentrations can be obtained, neither inside the core nor in the end region of the coil or in the transition therebetween. Moreover, the cooling of the transformer/reactor is accomplished.

Hereby, there will be a further advantage if the potential of the first semiconducting layer is generally equal to the potential of the conductor.

In connection hereto, it will be a further advantage if the second semiconducting layer is provided to generally form an equipotential surface, surrounding the conductor.

Hereby, another advantage will be obtained if at least two adjacent layers of the windings of the power transformer/reactor have generally equal coefficients of thermal expansion. Hereby, no fractures will appear in the windings when those are subjected to temperature changes.

In this context, it will be an advantage if the conductor comprises a number of strands, at least some of which are in electric contact with each other.

In this context, it will be a further advantage if each of said three layers is directly connected to adjacent layers along generally the whole contact surface.

In this context, it will be a further advantage if the winding/windings is/are formed by a cable, preferably a high voltage cable.

In this context, there will be a further advantage if the high voltage cable is given a conducting area of between 80 and 3000 mm^2 and an outer cable diameter of between 20 and 250 mm.

In this context, it will be an advantage if the high voltage cable comprises a metal shield or mantle.

There will be anoth r advantage in this context if the insulating conductor or the high voltage cable is flexible.

In this context, it will be an advantage if the layers are arranged to adhere to each other also when the insulating conductor or the high voltage cable is bent.

The use of such a cable means that the areas of the transformer-/reactor that are subjected to high electrical loads are delimited to the solid insulation of the cable. The rest of the transformer/reactor parts are only subjected to very decent electrical field strengths in the high voltage context. Moreover, the use of such a cable means that a plurality of the problem areas described during the definition of the background of the invention are eliminated. The insulation will be very simple. The construction time will be substantially shorter in comparison to the one of a conventional power transformer/reactor. The windings can be built separately, and the power transformer/reactor can be finally mounted on the operation spot.

However, the use of such a cable leads to new questions that have to be answered. The outer semiconducting layer must be directly grounded in or in the nearness of the two ends of the cable, so that the electric load which arises both during normal operation voltage and during transient sequences mainly shall burden only the solid insulation of the cable. The layer and these direct groundings form a closed circuit in which a current is induced during operation. In order to make the resistivity loss obtained in the layer negligible, the resistivity of the layer has to be sufficiently high.

Apart from this magnetically induced current, a capacitive current will flow through in the layer thanks to the direct grounding at the two ends of the cable. If the resistivity of the layer is chosen in such a way that it becomes too high, this capacitive current will become so delimited that the potential of parts of the layer can diverge so much from the ground pot ntial during a period of the alternating voltage that other areas of th power transform r/reactor than th solid insulation of the

winding is subjected to an electrical load. By directly grounding several points of the semiconducting layer, preferably one point for each turn of the winding, it is guaranteed that the whole outer layer will be at a grounding potential, and said problem will be eliminated if the conductivity of the layer is sufficiently high.

This one point grounding per turn of the outer shield can be accomplished by having grounding points positioned on a generatrix to a winding and by connecting the points along the axial length of the winding electrically and directly to a conducting ground rail which is then connected to the common ground potential.

In order to keep the losses in the outer layer as low as possible, a resistivity in the layer so high that it requires a plurality of grounding points per turn may be requested. Each turn on a winding is provided with an optional number, however equal for each turn, of grounding points of the outer layer. In the same way as the one point grounding of above, the grounding points can be positioned on a generatrix to the winding, and the points along the axial length of the winding are connected electrically and directly to conducting ground rails which are then connected to the common ground potential. However, it is presumptioned that the choice of grounding points is done in such a way that there will not be any magnetic currents induced in the connections to the grounding rails. In order to guarantee what is stated above, the connections between the grounding points and ground rails should pass through the core or yoke according to a preferred embodiment.

In extreme cases, the windings may be subjected to transient overvoltages which are so fast that parts of the outer semiconducting layer gets such a potential that other areas of the power transformer/reactor than the insulation of the cable are subjected to an undesired electrical load. In order to prevent such a situation from appearing, a number of non-linear elements, for example spark gaps, gas diodes, zener diodes, or varistors can be connected between the layer and ground for each turn of the winding. By connecting a capacitor between

th out r semiconducting layer and ground, it is also possible to prevent any undesired electrical load from appearing. A capacitor reduces the voltage load also at 50 Hz. These grounding principles will hereinafter be called "indirect grounding".

The individually grounded ground rails may be connected to ground via

1, a non-linear element, for example a spark gap or a gas diode,
2, a linear element parallel to a capacitor,
3, a capacitor

or a combination of these alternatives.

An advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if said liquid is a non-conducting liquid.

In this context, it is an advantage if the non-conducting liquid is an insulating oil.

An advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if the relative permittivity, e, of the liquid is relatively low, preferably $e \leq 10$.

Another advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if the relative permittivity, e, is relatively high, preferably $e>10$.

In this context, it is an advantage if the second semiconducting layer is grounded by or in the nearness of the two ends of each winding, and that a further point between the two ends is directly grounded.

An advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if said liquid is a low-conducting liquid.

In this context, it is an advantage if the low-conducting liquid has a specific resistivity, r, between 1 and 100 000 Wm.

Hereby, another advantage is obtained if the low-conducting liquid has a specific resistivity, r, between 10 and 10 000 Wm.

H reby, it is an advantage if the low-conducting liquid is comprised by water.

An advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if the layers are made of water tree resistant materials. Water trees are ageing phenomena in certain types of polymer insulation exposed to moisture and can result in an electric breakdown in the insulation.

According to the invention, another advantageous embodiment of the power transformer/reactor is obtained if there is a water-impermeable layer arranged around the second semiconducting layer.

According to the invention, another advantageous embodiment of the power transformer/reactor is obtained if the low-conducting liquid is comprised by an organic polar liquid.

Hereby, it is an advantage if the organic polar liquid is comprised by ethylene glycol, propylene glycol, ethylene carbonate or propylene carbonate.

Hereby, it is a further advantage if the organic polar liquid is supplemented with an additive for the adjustment of the conducting ability of the liquid.

Hereby, it is an advantage if said additive is comprised by quarternary ammonium salts.

According to the invention, an advantageous embodiment is obtained if the relative permittivity, e, of the liquid is relatively low, preferably $e \leq 10$.

According to the invention, another advantageous embodiment of the power transformer/reactor is obtained if the relative permittivity, e, is relatively high, preferably $e > 10$.

Hereby, it is an advantage if the container has the shape of acylinder with a toroidal cross-section.

Hereby, there is another advantage if said container is provided with $n(n \geq 2)$ electrically conducting members in contact with the liquid, said electrically conducting memb rs b ing separated by electrically in-

sulating materials, and ach of th m being directly grounded, said electrical connection being accomplished between the second semiconducting layers and said electrically conducting members.

According to the invention, an advantageous embodiment of the power transformer/reactor is obtained if the container is made of n electrically conducting sectors which are separated by n insulating intermediate sectors.

According to the invention, another advantageous embodiment of the power transformer/reactor is obtained if the container is made of electrically insulating materials, said n electrically conducting members being comprised by n electrodes of an electrically conducting material and being arranged at the inside of the container and in contact with the liquid.

According to the invention, another advantageous embodiment of the power transformer/reactor is obtained if n points ($n \geq 2$) are directly grounded by at least one turn of at least one winding.

Hereby, it is an advantage if the n directly grounded points are grounded in such a way that the electric connections between the n grounding points divide the magnetic flow into n parts in order to reduce the losses generated by the grounding.

Hereby, there is another advantage if the windings eclose a cross-sectional area A and if the circumference of each winding turn has the length l, where the electric connections between the n grounding points divide said cross-sectional area A in n sub-areas A_1, A_2 ...A_n such that

$$A = \sum_{i=1}^{n} A_i$$

and divide said length l into n segments l_1, l_2, ...l_n, such that

$$l = \sum_{i=1}^{n} l_i$$

and the electric connections between the n grounding points are constituted in such a way that the ends of each segment l_i are electrically connected in such a way that only the sub-area A_i is surrounded by a

loop consisting of the electric connection and th segment l_i, and the condition

$$\frac{\phi_i}{\phi} = \frac{l_i}{l}$$

is fulfilled, f_i being the magnetic flow through the sub-area A_i.

Hereby, it is an advantage if, when the magnetic flow density B is constant over the whole cross-section of the core, the electric connections between the n grounding points are arranged in such a way that the condition

$$\frac{A_i}{A} = \frac{l_i}{l}$$

is fulfilled.

Hereby, there is a further advantage if the second semiconducting layer is indirectly grounded at least one point between the two ends of each winding.

According to the invention, an advantageous embodiment of the power transformer/reactor is obtained if the indirect grounding is performed by means of a capacitor which is connected between the second semiconducting layer and ground.

According to the invention, another advantageous embodiment is obtained if the indirect grounding is performed by means of an element having a non-linear voltage-current characteristic and being connected between the second semiconducting layer and ground.

According to the invention, another advantageous embodiment of the power transformer/reactor is obtained if the indirect grounding is performed by means of a circuit which is connected between the second semiconducting layer and ground, and which comprises an element with a non-linear voltage-current characteristic and connected in parallel to a capacitor.

Hereby, it is an advantage if the indirect grounding is performed by means of a combination of the alternatives mentioned above.

Hereby, ther is a further advantage if the el ment with the non-linear voltage-current characteristic can be comprised by a spark gap, a diode filled with gas, a zener diode, or a varistor.

According to the invention, an advantageous embodiment of the power transformer/reactor is obtained if the power transformer/reactor comprises a core of a material which has a higher permeability than air.

According to the invention, another advantageous embodiment of the power transformer/reactor is obtained if the power transformer/reactor is provided without a core of a material with a higher permeability than air.

Hereby, it is an advantage if the winding/windings is/are flexible and if said layers bear on each other.

Hereby, there is a further advantage if said layers are made of materials having such an elasticity and such a relation between the coefficients of thermal expansion that the volume changes of the layers caused by temperature variations during operation can be absorbed by the elasticity of the materials in order to make the layers maintain their contact against each other despite the temperature variations that appear during operation.

Hereby, it is an advantage if the materials in said layers have a high elasticity.

The invention will now be explained more in detail by means of the following description of preferred embodiments thereof, with reference to the attached drawings.

Fig. 1 shows a cross-sectional view of a high voltage cable;

Fig. 2 schematically shows a first embodiment of the power transformer/reactor, according to the present invention;

Fig. 3 schematically shows a second embodiment of the power transformer/reactor according to the present invention;

Fig. 4 schematically shows a third embodiment of the power transformer/reactor according to the present invention;

Fig. 5 shows a perspective vi w of windings having three grounding points per turn, said windings being included in the power transformer/reactor according to the present invention;

Fig. 6 shows a perspective view of windings with one direct grounding point and two indirect grounding points per winding turn, said windings being included in the power transformer/reactor according to the present invention; and

Figs. 7a and 7b respectively show different elements for accomplishing an indirect grounding.

In fig. 1 a cross-sectional view of a high voltage cable 10 is shown, said cable traditionally being used for transmission of electrical power. The high voltage cable 10 shown may, for instance, be a standard 145 kV XLPE-cable without mantle and shield. The high voltage cable 10 comprises an electric conductor which may comprise one or more strands 12 which have a circular cross-section and are made of copper (Cu). These strands 12 are arranged in the middle of the high voltage cable 10. Around the strands 12, a first semiconducting layer 14 is arranged. Around the first semiconducting layer 14, there is arranged an insulation layer 16, for example XLPE-insulation. Around the insulation layer 16, a second semiconducting layer 18 is arranged. The three layers are arranged to adhere to each other even when the cable is bent. The cable shown is flexible, and this property is maintained during the entire life of the cable.

In fig. 2 a first embodiment of the power transformer/reactor according to the invention is schematically shown. The power transformer/reactor 100 comprises at least one winding (not shown; compare with figs 4 and 5), the winding/windings for example being provided with the high voltage cable 10 shown in fig. 1. The winding/windings is/are enclosed in a container 102 filled with liquid. In the embodiment shown in fig. 2, the container 102 is constituted by four electrically conducting members 104_1, 104_2, 104_3, 104_4. In this case, the electrically conducting members ar comprised by electrically conducting sectors 104_1, 104_2,

104_3, 104_4, which are in contact with th liquid in the container 102. The electrically conducting sectors 104_1, 104_2, 104_3, 104_4 are separated by electrically insulating materials, in this case in the shape of four insulating intermediate sectors 106_1, 106_2, 106_3, 106_4. The number of electrically conducting sectors and the number of electrically insulating sectors do not need to be 4. In a general case, there are $n(n \geq 2)$ electrically conducting sectors 104_1, 104_2, ... 104_n and n electrically insulating sectors 106_1, 106_2, ... 106_n. In the embodiment shown in fig. 2, the liquid is comprised by a low-conducting liquid. This results in an electric connection being accomplished between the winding/windings and said electrically conducting sectors 104_1, 104_2, 104_3, 104_4. If the winding/windings is/are provided with the high voltage cable 10 shown in fig. 1, a connection between the second semiconducting layers 18 (see fig. 1) and the electrically conducting sectors 104_1, 104_2, ... 104_n is accomplished. The liquid also accomplishes a cooling of the winding/windings. In this embodiment, the electrically conducting sectors 104_1, 104_2, 104_3, 104_4 are directly grounded 110 by means of the electric connections 108_1, 108_2, 108_3, 108_4. The electric connections (the leads) 108_1, 108_2, 108_3, 108_4 pass the core 112 (only schematically shown) in such a way that they divide the cross-sectional area A of the core 112 (and thereby the magnetic flow f) in four sub-areas A_1-A_4. By grounding in the way described above, the losses in the second semiconducting layer 18 (compare with fig. 1) are kept as low as possible. If the liquid also has a conducting ability so adjusted that the induced current in the liquid does not result in losses that are too high while, at the same time, the conducting ability is sufficient in order to accomplish the grounding of the second semiconducting layer of the high voltage cable, the problems regarding the cooling and grounding are simultaneously solved. The low-conducting liquid suitably has a specific resistivity, r, between 1and 100 000 Wm, preferably 10 and 10 000 Wm. For a further description of the principle of direct grounding, reference is made to fig. 5 and the description belonging ther to.

In fig 3 a s cond embodim nt of the power transformer/r actor according to the present invention is schematically shown. The power transformer/reactor 120 comprises at least one winding (not shown; compare with figs. 5 and 6), the winding/windings for example being provided with the high voltage cable 10 shown in fig. 1. The winding/windings is/are enclosed in a container 122 filled with liquid. In the embodiment shown in fig. 3, the container 122 is made of electrically isolating materials. The container 122 is also provided with four electrically conducting members 124_1, 124_2, 124_3, 124_4, which are constituted by four electrodes 124_1, 124_2, 124_3, 124_4 made of electrically conducting materials and arranged at the inside of the container 122 and in contact with the liquid. In a general case, there are $n(n \geq 2)$ electrodes 124_1, 124_2, ...124_n. In the embodiment shown in fig. 3, the liquid is comprised by a low-conducting liquid, such as in the case according to fig. 2. In this embodiment, the electrodes 124_1, 124_2, 124_3, 124_4 are directly grounded 110 by means of the electric connections 108_1, 108_2, 108_3, 108_4. In a way similar to the one of the embodiment according to fig. 2, the electric connections (leads) 108_1, 108_2, 108_3, 108_4 pass the core 112 (only schematically shown) in such a way that they divide the cross-sectional area A (and thereby the magnetic flow) of the core 112 into four sub-areas A_1-A_4. As to the rest, this embodiments works in the same way as the embodiment shown in fig. 2.

The containers 102, 122 shown in figs. 2 and 3 both have the shape of a cylinder with a toroidal cross-section. The containers 102, 122 are also provided with a cap and a bottom, as can be seen in figs. 2 and 3. In the containers 102, 122 shown, the core/core legs of the power transformre/reactor 100, 120 is/are arranged in the cylindrical hole 114 provided in the container 102, 122.

The containers 102, 122 may also be provided in one or two pieces without a separate bottom.

In fig. 4 a third embodiment of the power transformer/reactor according to th present invention is schematically shown. The power

transformer/r actor 130 comprises at least one winding (not shown; compare with figs. 5 and 6), the winding/windings for example being provided with the high voltage-cable 10 shown in fig. 1. The winding/windings is/are enclosed in a container 132 filled with liquid. As can be seen in fig. 4, the container 132 is provided with three cylindrical holes, 114_1, 114_2, 114_3, in which the core legs 134_1, 134_2, 134_3 are arranged. Even if it cannot be seen in fig. 4, the container 132 is provided with n electrically conducting members, either in the shape of n electrically conducting sectors, in correspondence to fig. 2 or in the shape of electrodes provided in contact with the liquid, in correspondence to fig. 3. In the embodiment shown in fig. 4, the liquid is comprised by a low-conducting liquid as in the cases according to figs. 2 and 3. In the same way as in figs. 2 and 3, the direct grounding is performed in such a way that the electric connections divide the cross-sectional area A (and thereby the magnetic flow) of the core legs 134_1, 134_2, 134_3 in n sub-areas A_1-A_n. As to the rest, this embodiment works in the same way as the embodiments shown in figs. 2 and 3.

In the embodiments of the power transformer/reactor 100, 120, 130 according to the present invention and shown in figs. 2-4, a low-conducting liquid was used. Depending on the properties of the liquid, two cases that require a different type of grounding can be obtained.

If the low-conducting liquid has a relative permittivity, e, which is relatively high, preferably e>10, the liquid will accomplish an indirect grounding or impulse grounding in a capacitive way. The only other grounding that is needed, is the direct grounding shown in fig.s 2 and 3. A suitable low-conducting liquid in this context is water. It is then suitable if the layers 14, 16, 18 (compare with fig. 1) are provided with water tree resistant materials. Here, another alternative is that a water impermeable layer is arranged between the insulating layer 16 and the second semiconducting layer 18. A low-conducting liquid with a high relative permittivity, e, can also be comprised by an organic polar liquid. Examples of organic polar liquids are ethylene glycol, propylen glycol, thyl-

ene carbonat or propyl ne carbonate. The organic polar liquid can also be supplemented with an additive for the adjustment of the conducting ability of the liquid. Said additive may, for example, be comprised by quarternary ammonium salts.

If, on the other hand, the low-conducting liquid has a relative permittivity, e, which is relatively low, preferably e≤10, the liquid will not accomplish a sufficiently effective indirect grounding or impulse grounding. In this case, the direct grounding shown in figs. 2-4 must be supplemented by an indirect grounding (compare with fig. 6). An example of such a low-conducting liquid with e≤10 is mineral oil with additives such as quarternary ammonium salts.

Further embodiments of the power transformer/reactor according to the present invention will be obtained if the liquid in the container is a non-conducting or isolating liquid. Depending on the properties of the liquid, it is also here possible to obtain two cases that require a different type of grounding.

If the non-conducting or isolating liquid has a relative permittivity, e, which is relatively high, preferably e>10, the liquid will accomplish an indirect grounding or impulse grounding in a capacitive way. Thanks to the high capacity towards the ground through the liquid, a capacitive impulse grounding is accomplished. Generally, the only further grounding needed is a direct grounding, however not exactly the one shown in fig. 2-4 (compare with fig. 5).

If, however, the non-conducting or isolating liquid has a relative permittivity, e, which is relatively low, preferably e≤10, the liquid will not accomplish an indirect grounding or impulse grounding. Accordingly, a direct grounding, however not exactly the one shown in figs. 2 and 3 (compare with fig. 5) as well as an impulse grounding or indirect grounding (compare with fig. 6) are required. If the liquid is a non-conducting or isolating liquid, the container has no electrically conducting members, because no electric connection can be accomplished in the liquid. An exampl of such a non-conducting liquid is an isolating oil. Examples of

such isolating oils are mineral oil, for example transform r oil, synthetic hydrycarbons, and silicon oil. The isolating liquid cools the power transformer/reactor but is neither used for direct nor indirect grounding.

In fig. 5, a perspective view of windings having three grounding points per turn is shown, said windings being included in the power transformer/reactor according to the present invention. In fig. 5 the reference number 20 indicates a core leg included in a power transformer or reactor. Around the core leg 20, two windings 22_1 and 22_2 are arranged, said windings being provided with the high voltage cable 10 shown in fig. 1. There are radially provided distance members 24_1, 24_2, 24_3, 24_4, 24_5, 24_6 in order to fix the windings 22_1 and 22_2. In the case shown in fig. 5, there are six distance members per winding turn. At the two ends 26_1, 26_2; 28_1, 28_2 of each winding 22_1, 22_2, the outer semiconducting layer is grounded (compare with fig. 1). The distance members 24_1, 24_3, 24_5 that are indicated with black are used to accomplish three grounding points per winding turn. These distance members 24_1, 24_3, 24_5 are thus connected to the second semiconducting layer of the high voltage cable 10. At the periphery of the winding 22_2 and along the axial length of the winding 22_2, the distance members 24_1 are directly connected to a first grounding element 30_1, the distance members 24_3 are directly connected to a second grounding element 30_2 and the distance members 24_5 are directly connected to a third grounding element 30_3. The grounding elements 30_1, 30_2, 30_3 can be comprised by grounding rails 30_1, 30_2, 30_3 connected to the common grounding potential 32. The three grounding elements 30_1, 30_2, 30_3 are connected by means of two electric connections 34_1, 34_2 (leads). The electric connection 34_1 is guided into a first slit 36_1 arranged in the core leg 20, and is connected to the grounding elements 30_2 and 30_2. The electric connection 34_2 is guided into a second slit 36_2 arranged in the core leg 20, and is connected to the grounding elements 30_1 and 30_3. The slits 36_1, 36_2 are arranged in such a way that they divide the cross-sectional area A (and ther by the magnetic flow f) of th cor leg 20 in three sub-areas A_1, A_2,

A_3. The slits 36_1, 36_2 thus divide the cor l g 20 in three parts 20_1, 20_2, 20_3. This results in no currents in connection to the grounding rails being magnetically induced. By grounding in the way described above, the losses in the second semiconducting layer are kept as low as possible. In fig. 6, a perspective view of windings is shown, said windings having one direct grounding point and two indirect grounding points per winding turn, and being included in a power transformer/reactor according to the present invention. In fig. 6 the reference number 20 indicates a core leg included in a power transformer or reactor. In this case, two windings 22_1 and 22_2 are arranged around the core leg 20, said windings being provided with the high voltage cable 10 shown in fig. 1. The windings 22_1, 22_2 are fixed by means of six distance members 24_1, 24_2, 24_3, 24_4, 24_5, 24_6 per winding turn. At the ends 26_1, 26_2; 28_1, 28_2 of each winding 22_1, 22_2 the second semiconducting layer is grounded (compare with fig. 1). In this case, the distance members 24_1, 24_3, 24_3 that are indicated with black are used to accomplish one direct and two indirect grounding points per winding turn. The distance members 24_1 are directly connected to a first grounding element 30_1, the distance members 24_3 are directly connected to a second grounding element 30_2 and the distance members 24_5 are directly connected to a third grounding element 30_3. As can be seen in fig. 6, the grounding element 30_1 is directly connected to ground 36, while the grounding elements 30_2, 30_3 are indirectly grounded. The grounding element 30_2 is indirectly grounded as it is connected to the ground in series and via the spark gap 34. The grounding element 30_3 is indirectly grounded as it is connected to the ground in series and via a circuit comprising a spark gap 38 connected in parallel to a capacitor 40. The spark gaps 34 and 38 are examples of a non-linear element, i.e. an element with a non-linear voltage-current characteristic.

In figs. 7a and 7b respectively, different elements for accomplishing indirect grounding are shown. In fig. 6a, the indirect grounding is accomplish by means of a circuit 50, which comprises an lement 52 with a

non-lin ar voltage-curr nt characteristic and connect d in parallel to a capacitor 54. In this case, the element 52 with non-linear voltage-current characteristic us comprised by a spark gap 52. The element 52 can also be comprised by a diode filled with gas, a zener diode, or a varistor. In fig. 6b, the indirect grounding is accomplished by a zener diode 56.

In practice, the above defined principles of the direct and indirect grounding are executed in somewhat different ways depending on the properties of the liquid being used. Four different cases are obtained:

- The winding/windings is/are submerged into a non-conducting liquid with a low relative permittivity, e. The direct grounding is executed in accordance with fig. 5 and the indirect grounding is executed in accordance with fig. 6.
- The winding/windings is/are submerged into a non-conducting liquid with a high relative permittivity, e. The direct grounding is executed in accordance with fig. 5, while the indirect grounding is accomplished through the high capacity towards ground thanks to the liquid.
- The winding/windings are submerged in a low-conducting liquid with a high relative permittivity, e. First, a container according to figs. 2-4 and having electrically conducting members is used. The indirect grounding is accomplished thanks to the high capacity towards the ground thanks to the liquid. The direct grounding is accomplished partly according to the principle as per fig. 5. The difference is that, when the liquid is only fairly conducting, no special grounding elements 30 are needed (compare with fig. 5). The contact to the ground is established evenly along all the cable between the second/outer semiconducting layer of the cable and the low-conducting liquid. The current will then go to the electrically conducting members 102/124 where it is "caught" and led to the ground. On the other hand, the electrically conducting members are connected to ground in the way shown in figs. 2-5.
- Th winding/windings is/are submerged in a low-conducting liquid with a low r lative permittivity, e. Also in this cas , a contain r ac-

cording to figs. 2-4 and equipped with electrically conducting members is used. The direct grounding is accomplished partly in accordance with the principle of fig. 5, and the indirect grounding is accomplished partly in accordance with fig. 6. The difference is that, when the liquid is a low-conducting one, no special grounding elements 30 are needed (compare with figs. 5 and 6). The contact with the ground is established evenly along the whole cable between the second/outer semiconducting layer of the cable and the low-conducting liquid. The current then goes to the electrically conducting members 102/124, where it is "caught" and led to the ground. On the other hand, the electrically conducting members are connected to indirect ground and to direct ground in the ways shown in figs. 2-6.

On the other hand, it should be stated that all the grounding methods mentioned above, direct or indirect ones, through the liquid or by means of separate devices, are combined or can be present at the same time.

In the figures shown above, the power transformer/reactor comprises a magnetizable core. In this case, it should be said that the power transformer/reactor may comprise a core made of material that has a higher permeability than air. It may also be provided without a core of a material that has a higher permeability than air.

The invention is not delimited to the embodiments shown above, but several modifications are possible within the frame of the enclosed claims.

CLAIMS

1. A power transformer/reactor (100;120) comprising at least one winding (22_1, 22_2), **characterized** in that the winding/windings (22_1, 22_2) comprises/comprise at least one electric conductor, a first semiconducting layer (14) arranged around the conductor, an insulating layer (16) arranged around the first semiconducting layer (14), and a second semiconducting layer (18) arranged around the insulating layer (16), and in that the winding/windings (22_1, 22_2) is/are enclosed in a container (102; 122) filled with a liquid which accomplishes a cooling.

2. A power transformer/reactor (100; 120) according to claim 1, **characterized** in that the potential of the first semiconducting layer (14) is generally the same as the potential of the conductor.

3. A power transformer/reactor (100; 120) according to claim 1 or 2, **characterized** in that the second semiconducting layer (18) is arranged to generally form an equipotential surface surrounding the conductor.

4. A power transformer/reactor (100; 120) according to any one of claims 1-3, **characterized** in that at least two adjacent layers of the windings of the power transformer/reactor have generally equal coefficients of thermal expansion.

5. A power transformer/reactor (100; 120) according to any one of the preceding claims, **characterized** in that the conductor comprises a number of strands (12), at least some of which are in electric contact with each other.

6. A power transformer/reactor (100; 120) according to any one of patent claims 1-5, **characterized** in that each of said three layers is di-

r ctly connected to adjac nt layers along g n rally the whole contact surface.

7. A power transformer/reactor (100; 120) according to any one of claims 1-6, **characterized** in that the winding/windings (22_1, 22_2) is/are formed by a cable, preferably a high voltage cable (10).

8. A power transformer/reactor (100; 120) according to claim 7, **characterized** in that the high voltage cable (10) is produced with a conductor area between 80 and 3000 mm^2 and an outer cable diameter between 20 and 250 mm.

9. A power transformer/reactor (100; 120) according to claim 7 or 8, **characterized** in that said high voltage cable (10) comprises a metal shield or mantle.

10. A power transformer/reactor (100; 120) according to any one of claims 1-9, **characterized** in that the insulating conductor or high voltage cable (10) is flexible.

11. A power transformer/reactor (100; 120) according to claim 10, **characterized** in that the layers are provided to adhere to each other also when the insulating conductor or the high voltage cable (10) is bent.

12. A power transformer/reactor (100; 120) according to any one of the preceding claims, **characterized** in that said liquid is a non-conducting liquid.

13. A power transformer/reactor (100; 120) according to claim 12, **haracteriz d** in that said non-conducting liquid is an insulating oil.

14. A power transformer/reactor (100; 120) according to claim 12 or 13, **characterized** in that the relative permittivity, e, of the liquid is relatively low, preferably e≤10.

15. A power transformer/reactor (100; 120) according to claim 12 or 13, **characterized** in that the relative permittivity, e, of the liquid is relatively high, preferably e>10.

16. A power transformer/reactor (100; 120) according to claim 14 or 15, **characterized** in that the second semiconducting layer (18) is grounded at or in the nearness of the two ends (26_1, 26_2; 28_1, 28_2) of each winding (22_1, 22_2), and that another point between the two ends (26_1, 26_2; 28_1, 28_2) is directly grounded.

17. A power transformer/reactor (100; 120) according to any one of claims 1-11, **characterized** in that said liquid is a low-conducting liquid.

18. A power transformer/reactor (100; 120) according claim 17, **characterized** in that the low-conducting liquid has a specific resistivity, r, between 1 and 100 000 Wm.

19. A power transformer/reactor (100; 120) according to claim 18, **characterized** in that the low-conducting liquid has a specific resistivity, r, between 10 and 10 000 Wm.

20. A power transformer/reactor (100; 120) according to any one of claims 17-19, **characterized** in that the low-conducting liquid is comprised by water.

21. A power transformer/reactor (100; 120) according to claim 20, **characterized** in that the layers (14, 16, 18) are made of water tree resistant materials.

22. A power transformer/reactor (100; 120) according to claim 20, **characterized** in that, a water-impermeable layer is arranged around the second semiconducting layer (18).

23. A power transformer/reactor (100; 120) according to claims 17-19, **characterized** in that the low-conducting liquid is constituted by an organically polar liquid.

24. A power transformer/reactor (100; 120) according to claim 23, **characterized** in that the organically polar liquid is comprised by ethylene glycol, propylene glycol ethylene carbonate or propylene carbonate.

25. A power transformer/reactor (100; 120) according to claim 24, **characterized** in that the organically polar liquid is supplemented with an additive for adjusting the conducting capability of the liquid.

26. A power transformer/reactor (100; 120) according to claim 25, **characterized** in that said additive is comprised by quarternary ammonium salts.

27. A power transformer/reactor (100; 120) according to any one of claims 17-19, **characterized** in that the relative permittivity, e, of the liquid is relatively low, preferably $e \leq 10$.

28. A power transformer/reactor (100; 120) according to any one of claims 17-26, **characterized** in that the relative permittivity, e, of the liquid is relatively high, preferably $e > 10$.

29. A power transformer/reactor (100; 120) according claim 27 or 28, **characterized** in that the container (102; 122) has the shape of a cylinder with a toroidal cross-section.

30. A power transformer/reactor (100; 120) according to claim 29, **characterized** in that said container (102; 122) is provided with n ($n \geq 2$) electrically conducting members (104_1- 104_n; 124_1-124_n) in contact with the liquid, said electrically conducting members (104_1- 104_n; 124_1-124_n) being separated by an electrically insulating materials, and each of them being grounded, and electrical connection being accomplished between the second conducting layers (18) and said electrically semiconducting members (104_1- 104_n; 124_1-124_n).

31. A power transformer/reactor (100) according to claim 30, **characterized** in that the container (102) is constituted by n electrically conducting sectors (104_1-104_n), separated by n insulating intermediate sectors (106_1-106_n).

32. A power transformer/reactor (120) according to claim 30, **characterized** in that the container (122) is made of an electrically insulating material, the n conducting members being comprised by n electrodes (124_1-124_n) of an electrically conducting material, arranged at the inside of the container and in contact with the liquid.

33. A power transformer/reactor (100; 120) according to claim 16, **characterized** in that, n points ($n \geq 2$) are directly grounded by at least one turn of at least one winding (22_1, 22_2).

34. A power transformer/reactor (100; 120) according to any one of claims 30-33, **characterized** in that the n directly grounded points are grounded in such a way that the electric connections between the n grounding points divide the magnetic flow into n parts in order to delimit the losses generated due to the grounding.

35. A power transformer/reactor (100; 120) according to claim 34, where the windings enclose a cross-sectional area A, and the circumference of each winding turn has the length l, the electric connections (34_1, 34_2, ..., 34_{n-1}) between the n grounding points dividing said cross-sectional area into n subareas A_1, A_2, ... A_n, such that

$$A = \sum_{i=1}^{n} A_i$$

and dividing said length l into n segments l_1, l_2, ..., l_n, such that

$$l = \sum_{i=1}^{n} l_i$$

characterized in that the electric connections between the n grounding points are provided in such a way that the ends of each segment l are electrically connected such that only the subarea A_1 is surrounded by a loop comprised by the electric connection no. i and the segment l_i, and such that the condition

$$\frac{\phi_i}{\phi} = \frac{l_i}{l}$$

is fulfilled, f_i being the magnetic flow through the subarea A.

36. A power transformer/reactor (100; 120) according to claim 35, by which the magnetic flow density B is constant across the whole cross-section of the core, **characterized** in that the electric connections between the n grounding points are provided in such a way that the condition

$$\frac{A_i}{A} = \frac{l_i}{l}$$

is fulfilled.

37. A power transformer/reactor (100; 120) according to any one of claims 34-36, when being dependent of claim 14 or 27, **characterized** in that second semiconducting layer (18) is indirectly grounded at at least one point between the two ends (26_1, 26_2; 28_1, 28_2) of each winding (22_1, 22_2).

38. A power transformer/reactor (100; 120) according to claim 37, **characterized** in that the indirect grounding is executed by means of a capacitor connected between the second semiconducting layer (18) and ground.

39. A power transformer/reactor (100; 120) according to claim 37, **characterized** in that the indirect grounding is performed by means of an element (34) having a non-linear voltage-current characteristic and connected between the second semiconducting layer (18) and ground.

40. A power transformer/reactor (100; 120) according to claim 37, **characterized** in that the indirect grounding is performed by means of a circuit (38, 40) connected between the second semiconducting layer (18) and ground, said circuit comprising an element (38) having a non-linear voltage-current characteristic and connected in parallel to a capacitor (40).

41. A power transformer/reactor (100; 120) according to claim 40, **characterized** in that the indirect groundings are provided by means of a combination of the alternatives according to claims 38-40.

42. A power transformer/reactor (100; 120) according to any one of claims 39-41, **characterized** in that the elements that have a non-linear voltage-current characteristic may be comprised by a spark gap (34, 38, 52), a diode filled with gas, a zener diod (56) or a varistor.

43. A power transformer/reactor (100; 120) according to any one of claims 1-42, **characterized** in that the power transformer/reactor comprises a core of a material having a higher permeability than air.

44. A pow r transform r/reactor (100; 120) according to any on of claims 1-43, **characterized** in that the power transformer/reactor is provided without a core of a material having a higher permeability than air.

45. A power transformer/reactor (100; 120) according to claim 1, **characterized** in that the winding/windings (22_1, 22_2) is/are flexible, and in that said layers bear on each other.

46. A power transformer/reactor (100; 120) according to claim 45, **characterized** in that said layers are made of materials having such an elasticity and such a relation between the coefficients of thermal expansion of the materials that the volume changes of the layers due to temperature variations during operation can be absorbed through the elasticity of the materials, such that the layers maintain their mutual contact by the temperature variations appearing during operation.

47. A power transformer/reactor (100; 120) according to claim 46, **characterized** in that the materials in said layers have a high elasticity.

Fig. 1

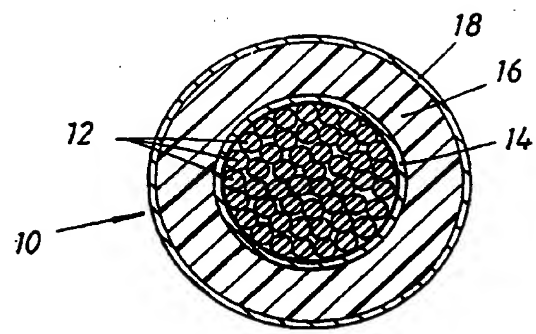


Fig. 2

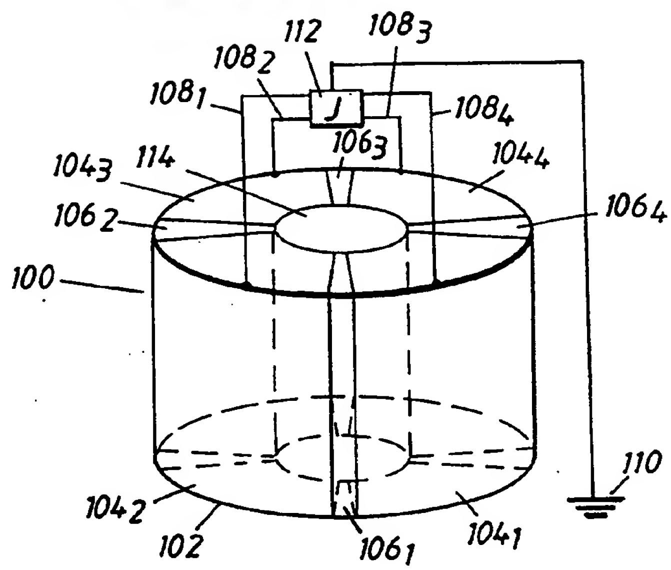


Fig. 3

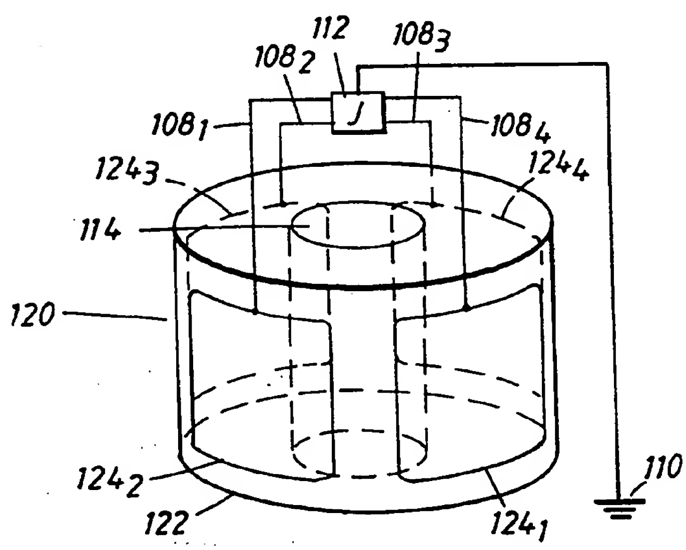


Fig. 4

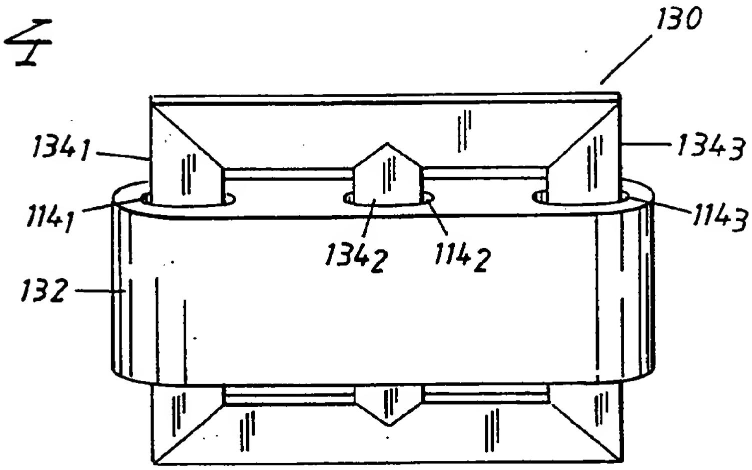

130
134_1
134_3
114_1
114_3
134_2
114_2
132

Fig. 5

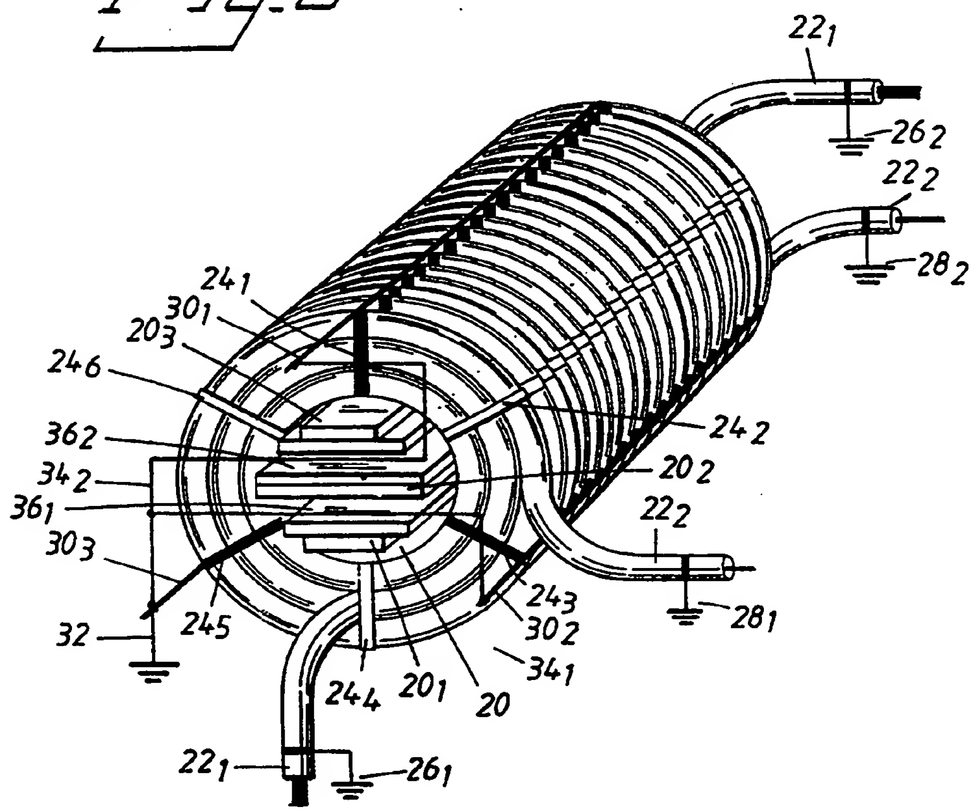

22_1
26_2
22_2
28_2
24_1
30_1
20_3
24_6
36_2
24_2
34_2
20_2
36_1
22_2
30_3
24_3
30_2
28_1
32
24_5
34_1
24_4
20_1
20
22_1
26_1

Fig. 6

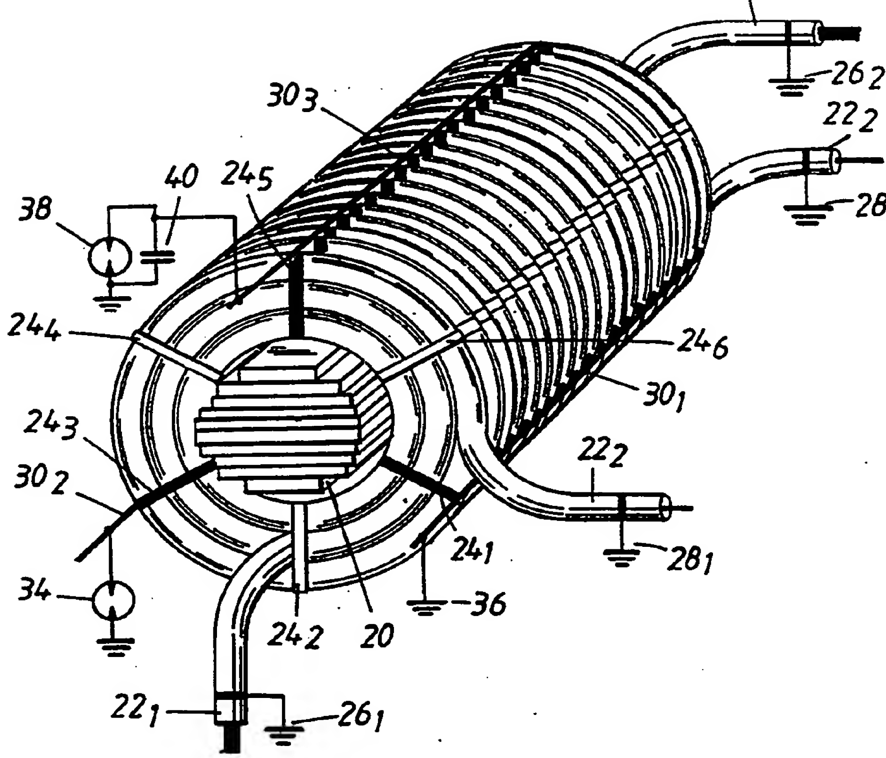


Fig. 7a

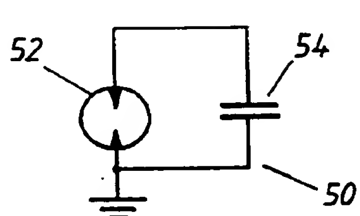


Fig. 7b